Illumination System with Field Mirrors for Producing Uniform Scanning Energy

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an illumination system, and more particularly to an illumination system for EUV lithography with wavelengths less than 193 nm.

2. Description of the Prior Art

To reduce the structural widths for electronic components, especially in the submicron range, it is necessary to reduce the wavelength of the light used for microlithography. For example, lithography with soft x-rays is conceivable with wavelengths smaller than 193 nm. US-A 5,339,346 disclosed an arrangement for exposing a wafer with such radiation. An illumination system for soft x-rays, so-called EUV radiation, is shown in US-A 5,737,137, in which illumination of a mask or a reticle to be exposed is produced using three spherical mirrors.

Field mirrors that show good uniformity of output of an exposure beam at a wafer in a lithographic system have been disclosed in US 5142561. The exposure systems described therein concern the contact exposure of a wafer through a mask with high-energy x-rays of 800 to 1800 eV.

EUV illumination systems for EUV sources have been disclosed in EP 99 106 348.8 (US application serial no. 09/305017) and PCT/EP99/02999. These illumination systems are adapted to

synchrotron, wiggler, undulator, Pinch-Plasma or Laser-Produced-Plasma sources.

Scanning uniformity is a problem of the aforementioned scanning exposure systems in illuminating a slit, particularly a curved slit. For example, the scanning energy obtained as a line integral over the intensity distribution along the scan path in a reticle or wafer plane may increase toward the field edge despite homogeneous illumination intensity because of the longer scan path at the field edge for a curved slit. However, scanning energy and with it scanning uniformity may also be affected by other influences, for example coating or vignetting effects are possible. The curved slit is typically represented by a segment of a ring field, which is also called an arc shaped field. The arc shaped field can be described by the width delta r, a mean Radius R_0 and the angular range $2 \cdot \alpha_0$. For example, the rise of the scanning energy for a typical arc shaped field with a mean radius of R = 100 mm and an angular range of $2 \cdot \alpha_0 = 60°$ is 15%.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an illumination system for a projection exposure system in which the scanning energy is uniform, or can be controlled to fit a predetermined curve.

This and other objectives of the present invention are achieved by shaping a field lens group in an illumination system of a generic type so that the illuminated field is distorted in an image plane of the illumination system perpendicular to the scanning direction. In

this plane the mask or reticle of a projection exposure system is located.

The term "field lens group" is taken to describe both field mirror(s) and field lens(es). For wavelengths $\lambda > 100nm$ the field lens group typically comprises refractive field lens(es), but mirrors are also possible. For wavelengths in the EUV region ($10nm < \lambda < 20nm$) the field lens group comprises reflective field mirror(s). EUV lithography uses wavelengths between 10nm and 20nm, typically 13nm.

According to the present invention it is possible to determine the necessary distortion to obtain a predetermined intensity distribution. It is advantageous for a scanning system to have the capability of modifying the intensity distribution perpendicular to the scanning direction to get a uniform distribution of scanning energy in the wafer plane. The scanning energy can be influenced by varying the length of the scanning path or by modifying the distribution of the illumination intensity. The present invention relates to the correction of the distribution of the illumination intensity. In comparison to stepper systems where a two-dimensional intensity distribution has to be corrected, a scanner system only requires a correction of the distribution of the scanning energy.

In one embodiment of the present invention, the illumination intensity decreases from the center of the field to the field edges by means of increasing distortion. The intensity is maximum at the field center ($\alpha = 0°$) and minimum at the field edges ($\alpha = \pm\alpha_0$). A decrease of the illumination intensity towards the field edge permits a compensation for an increase of the scan path so that the scanning energy remains homogeneous.

The present invention also provides for the illumination intensity to increase from the center of the field to the field edges by means of decreasing distortion. This correction can be necessary if other influences like layer or vignetting effects lead to a decreasing scanning energy towards the field edges.

Preferably, the field lens group is designed so that uniformity of scanning energy in the range of ± 7%, preferably ± 5%, and very preferably ± 3%, is achieved in the image plane of the illumination system.

The field lens group is shaped so, that the aperture stop plane of the illumination system is imaged into a given exit pupil of the illumination system. In addition to the intensity correction, the field lens group achieves the correct pupil imaging. The exit pupil of the illumination system is typically given by the entrance pupil of the projection objective. For projection objectives, which do not have a homocentric entrance pupil, the location of the entrance pupil is field dependent. In such a case, the location of the exit pupil of the illumination system is also field dependent.

The shape of the illuminated field according to this invention is rectangular or a segment of a ring field. The field lens group is preferably shaped such that a predetermined shaping of the illuminated field is achieved. If the illuminated field is bounded by a segment of a ring field, the design of the field lens group determines the mean radius R_0 of the ring field.

It is advantageous to use a field lens group having an anamorphotic power. This can be realized with toroidal mirrors or

lenses so that the imaging of the x- and y-direction can be influenced separately.

In EUV systems the reflection losses for normal incidence mirrors are much higher than for grazing incidence mirrors. Accordingly, the field mirror(s) is (are) preferably grazing incidence mirror(s).

In another embodiment of the present invention the illumination system includes optical components to transform the light source into secondary light sources. One such optical component can be a mirror that is divided into several single mirror elements. Each mirror element produces one secondary light source. The mirror element can be provided with a plane, spherical, cylindrical, toroidal or an aspheric surface. Theses single mirror elements are called field facets. They are imaged in an image plane of the illumination system where the images of the field facets are at least partly superimposed.

For extended light sources or other purposes it can be advantageous to add a second mirror that is divided in several single mirror elements. Each mirror element is located at a secondary light source. These mirror elements are called pupil facets. The pupil facets typically have a positive optical power and image the corresponding field facets into the image plane.

The imaging of the field facets into the image plane can be divided into a radial image formation and an azimuthal image formation. The y-direction of a field facet is imaged in the radial direction, and the x-direction is imaged in the azimuthal direction of an arc shaped field. To influence the illumination intensity

perpendicular to the scanning direction the azimuthal image formation will be distorted.

The imaging of the field facets is influenced by the field lens group. It is therefore advantageous to vary the azimuthal distortion by changing the surface parameters of the components of the field lens group.

The field lens group is shaped such that the secondary light sources produced by the field facets are imaged into a given exit pupil of the illumination system.

With a static design of the field lens group, a given distribution of the illumination intensity, the shaping of the illuminated field and the pupil imaging can be realized. The effects that are known can be taken into account during the design of the field lens group. But there are also effects that cannot be predicted. For example, the coatings can differ slightly from system to system. There are also time dependent effects or variations of the illumination intensity due to different coherence factors, so called setting dependent effects. Therefore, actuators on the field mirror(s) are preferably provided in order to control the reflective surface(s).

The distortion, and thus the illumination intensity, can be modified using the actuators. Since the surface changes also affect the pupil imaging, intensity correction and pupil imaging are regarded simultaneously. The surface changes are limited by the fact that the directions of centroid rays that intersect the image plane are changed less than 5mrad, preferably less than 2mrad, and very preferably less than 1mrad.

It is advantageous to reduce the number of surface parameters to be controlled. To influence the illumination intensity, and thus the scanning intensity, only the surface parameters that influence the shape of the mirror surface(s) perpendicular to the scanning direction will be modified. These are the x-parameters if the scanning direction is the y-direction.

A particularly simple arrangement is obtained when the actuators for controlling the field mirror surface are placed parallel to the scan direction or the y-axis of the field mirror, for example in the form of a line or beam actuator.

The present invention also provides for a projection exposure system for microlithography using the previously described illumination system. A mask or reticle is arranged in the image plane of the illumination system, which is also an interface plane between the illumination system and projection system. The mask will be imaged into a wafer plane using a projection objective.

The illumination of the wafer is typically telecentric. This means that the angles of the chief rays regarding the wafer plane are smaller than ±5mrad. The angle distribution of the chief rays in the reticle plane is given by the lens design of the projection objective. The directions of the centroid rays of the illumination system must be well adapted to the directions of the chief rays of the projection system in order to obtain a continuous ray propagation. The telecentricity requirement is fulfilled in this invention when the angular difference between the centroid rays and the chief rays does not exceed a given degree in the plane of the reticle, for example ± 10.0 mrad, preferably ± 4.0 mrad, and very preferably 1.0mrad.

For scanning lithography it is very important that the scanning energy in the wafer plane is uniform. With the previously described illumination system it is possible to achieve uniformity values of scanning energy in the wafer plane in the range of ± 7%, preferably ± 5%, and very preferably ± 3%.

The present invention also provides for a method for calculating the magnification β_s for the azimuthal imaging of the field facets for a predetermined distribution of scanning energy. With the knowledge of the azimuthal magnification β_s the design of the field lens group can be determined.

If the predicted distribution of scanning energy in the wafer plane is not obtained, the scanning energy can be corrected using the actuators of the field mirror(s). From the difference between the predicted and measured distribution of scanning energy the magnification for the azimuthal imaging of the field facets, and thus the necessary surface corrections, can be calculated.

The present invention will be more fully understood from the detailed description given hereinafter and the accompanying drawings, which are given by way of illustration only and are not be considered as limiting the present invention. Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will be apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph of an arc shaped field for an EUV illumination system;

Fig.2 is a side view of an EUV illumination system, in accordance with the present invention;

Fig. 3 is a top perspective view of an imaging of a central field facet to a plane of a reticle using pupil facets and field mirrors in accordance with the present invention;

Fig. 4 is an illustration of a transformation of a rectangular field in an arc shaped field in accordance with the present invention;

Fig. 5 is a graph of a calculated curve of an integral scanning energy in a plane of a reticle considering a central field facet in accordance with the present invention;

Fig. 6 is a graph of a simulated curve of an integral scanning energy in a plane of a reticle simulated with all field facets in accordance with the present invention;

Fig. 7 is a graph of a sagitta difference on a first field mirror with and without distortion correction with variation of R_x, R_y, K_x, K_y, in accordance with the present invention;

Fig. 8 is a graph of a sagitta difference on a second field mirror with and without distortion correction with variation of R_x, R_y, K_x, K_y, in accordance with the present invention;

Fig. 9 is a graph of a sagitta difference on a first field mirror with and without distortion correction with variation of only a conic constants K_x, in accordance with the present invention;

Fig. 10 is a graph of a sagitta difference on a second field mirror with and without distortion correction with variation of only a conic constants K_x, in accordance with the present invention

Fig. 11 is a graph of an arrangement of actuators for dynamic control of a surface form of a second field mirror in plan view and side view; and

Fig. 12 is a side view of an EUV projection exposure system in accordance with the present invention.

DESCRIPTION OF THE INVENTION

The illumination systems pursuant to the invention described below illuminate a segment of a ring field as shown in Figure 1. An arc shaped field 11 in a reticle plane is imaged into a wafer plane by a projection objective.

According to Fig. 1, the width of the arc shaped field 11 is Δr and the mean radius is R_0. The arc shaped field extends over an angular range of

$$2 \cdot \alpha_0$$

and an arc of

$2 \cdot s_0$.

The angle α_0 is defined from the y-axis to the field edge, the arc length s_0 is defined from the center of the field to the field edge along the arc at the mean radius R_0.

The scanning energy SE(x) at x is found to be the line integral over the intensity E(x,y) along the scan direction, which is the y-direction in this embodiment:

$$SE(x) = \int_{x=const} E(x,y)dy$$

in which E(x,y) is the intensity distribution in the x-y plane.

Each point on the reticle or wafer contains the scanning energy SE(x) corresponding to its x coordinate. If uniform exposure is desired, it is advantageous for the scanning energy to be largely independent of x. In photolithography, it is desirable to have a uniform scanning energy distribution in the wafer plane. The resist on the wafer is very sensitive to the level of light striking the wafer plane. Preferably, each point on the wafer receives the same quantity of light or the same quantity of scanning energy.

As described below, the scanning energy can be controlled by the design of the field lens group. By way of example, an EUV illumination system is shown in Figure 2. In this embodiment a Laser-Produced-Plasma source 200 is used to generate the photons at λ = 13nm. The light of the source is collected with an ellipsoidal mirror 21 and directed to a first mirror 22 comprising several rectangular mirror elements. The single mirror elements are called

field facets, because they are imaged in an image plane 26 of the illumination system. In this embodiment the field facets are plane mirror elements in which each field facet is tilted by a different amount. The ellipsoidal mirror 21 images the light source 200 in an aperture stop plane 23. Due to the tilted field facets, the image of the light source is divided into several secondary light sources 201 so that the number of secondary light sources 201 depends on the number of tilted field facets. The secondary light sources 201 are imaged in an exit pupil 27 of the illumination system using a field mirror 24 and a field mirror 25. The location of the exit pupil 27 depends on the design of the projection objective, which is not shown in Figure 2. In this embodiment, the field mirrors 24 and 25 are grazing incidence mirrors with a toroidal shape. The imaging of the field facets in the image plane 26 is influenced by the field mirrors 24 and 25. They introduce distortion to shape the arc shaped images of the rectangular field facets and to control the illumination intensity in the plane of the image plane 26, where a reticle is typically located. This will be further explained below. The tilt angles of the field facets are chosen to overlay the arc shaped images of the field facets at least partly in the image plane 26.

The embodiment of Figure 2 is only an example. The source is not limited to Laser-Produced-Plasma sources. Lasers for wavelength ≤ 193nm, Pinch Plasma sources, synchrotrons, wigglers or undulators for wavelength between 10-20nm are also possible light sources. The collector unit is adapted for the angular and spatial characteristic of the different light sources. The illumination system does not need to be purely reflective. Catadioptric or dioptric components are also possible.

Figure 3 shows, in a schematic three-dimensional view, the imaging of one field facet 31 to an image plane 35. The beam path of this central field facet 31 located on the optical axis is representative of all other field facets. An incoming beam 300 is focused to a secondary light source 301 using the field facet 31. The field facet 31 is in this case a concave mirror element. The secondary light source 301 is spot-like if a point source is used. The beam diverges after the secondary light source 301. Without a field mirror 33 and a field mirror 34, the image of the rectangular field facet 31 would be rectangular. The imaging of the field facet 31 is distorted to produce an arc shaped field 302. The distortion is provided by the field mirrors 33 and 34. Two mirrors are necessary to produce the proper orientation of the arc. A reflected beam 303 is focused at the exit pupil of the illumination system using the field mirrors 33 and 34. The exit pupil is not shown in Figure 3. The field mirrors 33 and 34 image the secondary light source 301 into the exit pupil.

For real sources the secondary light source 301 is extended. To get a sharp image of the field facet 31 it is advantageous to image the field facet 31 into the image plane 35 using another mirror 32. The mirror 32 located at the secondary light source 301 is called a pupil facet and has a concave surface. Each secondary light source has such a pupil facet. Figure 3 shows a light path for one pair of field facet 31 and pupil facet 32. In a case of a plurality of field facets 31, there is a corresponding number of pupil facets 32, which are located at the plane of the secondary light sources. In such a case, the plurality of mirror elements 32 forms another faceted mirror.

The term "entendue" refers to a phase-space volume of a light source. Pupil facets are necessary only for extended light sources,

which have a high entendue value. In the case of a point source, the secondary light source is also a point, and a pupil facet would have no influence on the imaging. In Figure 2 the source diameter of the Laser-Produced-Plasma source 200 is only 50μm, so the pupil facets are not required. For higher source diameters the mirror with the pupil facets is added at the aperture stop plane 23. To eliminate vignetting, the tilt angle of the mirror 22 with the field facets is increased.

The field mirrors 24, 25, 33, 34 shown in Figures 2 and 3 form the arc shaped field 302, image the plane of the aperture stop 23 in the exit pupil plane 27 of the illumination system, and control the illumination distribution in the arc shaped field 302.

As will be described in the following paragraphs, the imaging of the central field facet 31 shown in Figure 3 is used to optimize the design of the field mirrors 33 and 34. The form of the images of other field facets is determined by a field lens group nearly in the same way as for the central field facet 31. Thus, the design of the field lens group, which in turn controls the scanning energy, can be optimized through the imaging of the central field facet 31. This facet can be considered as a homogeneously radiating surface. In the real system with all field facets homogeneity results from the superimposition of the images of all field facets.

When optimizing the design of the field lens group, the goals include controlling the scanning energy, producing an arc shaped field, and imaging of the plane with secondary light sources to an exit pupil of the illumination system. The given components include a first mirror with field facets 31, a second mirror with pupil facets 32, a field lens group including mirror 33 and mirror 34, image plane 35 and an exit pupil plane (not shown in Figure 3). The

field lens group, in this case the shapes of mirror 33 and mirror 34, will be designed. Without the field lens group, the shape of the illuminated field in image plane 35 would be rectangular, the illuminated field would not be distorted, and there would be no pupil imaging.

As a first step, the complexity of the process of designing the field lens group is reduced by considering the imaging of only the central field facet 31, rather than considering all of the facets. Facet 31 is imaged to image plane 35 using pupil facet 32. The design of the field lens group requires (1) controlling the scanning energy by introducing distortion perpendicular to the scanning direction, (2) producing an arc shaped field, and (3) imaging the secondary light sources 301 to the exit pupil of the illumination system. The field lens group only influences the field facet imaging by distorting this imaging. The main component of the field facet imaging is due to the pupil facet 32 (or to a camera obscura).

As a second step, a simulation is constructed for all the field facets, the pupil facets and the field lens group designed in the first step. Normally, the field lens group influences the imaging of the other field facets in a manner similar to that of the imaging of the central field facet. If the imaging is not similar, the design of the field lens group must be corrected. Such corrections are typically small.

A superimposition of the images of all field facets results in intensity homogeneity in the image plane. This is similar to the principle of a fly-eye integrator. Since the central field facet is representative of all field facets, design complexity is reduced by considering only the central field facet. To simulate the intensity distribution in the image plane only with a central light channel

defined by field facet 31 and pupil facet 32, the central field facet 31 is regarded as a homogeneous radiating surface.

Figure 4 shows, schematically, an imaging of a rectangular field 41 on an arc shaped field 42 at an image plane of an illumination system. The rectangular field 41 can be a homogeneously radiating real or virtual surface in a plane conjugated to a reticle plane. Figure 4 shows the correlation between rectangular field 41 and arc shaped field 42, and it also shows the orientation and definition of the coordinate system. The description of the scanning energy control, as set forth in the following pages, is independent of the design layout of the field facets or pupil facets. Accordingly, only a homogeneously radiating rectangular field is being considered. In Figure 3, the rectangular field is given by central field facet 31.

A length x_W at the rectangular field 41 is imaged on an arc length s at the arc shaped field 42, and a length y_W is imaged on a radial length r. The origin of the coordinate systems is the center of the field for the rectangular field 41 and the optical axis for the arc shaped field 42.

When the field lens group consists of mirror(s) or lens(es) with anamorphotic power, for example toroidal mirrors or lenses, the image formation can be divided into two components β_s and β_{rad}:

$$\beta_s : x_w \rightarrow s$$

$$\beta_{rad} : y_w \rightarrow r$$

wherein

β_{rad}: radial imaging of y_W on r

β_s: azimuthal imaging of x_W on s

(x_W, y_W): horizontal and vertical coordinates of a field point on the rectangular field 41.

(s, r): radial and azimuthal coordinates of a field point on the arc shaped field 42.

Assuming a homogeneous intensity distribution

$$E_w(x,y) = E_w^0$$

in the x-y plane of the rectangular field, the intensity distribution

$$E_r(s,r)$$

in the plane of the arc shaped field 42 is obtained by the influence of the field lens group. The index w below stands for the plane of the rectangular field, the index r below stands for the plane of the arc shaped field. If the azimuthal image formation β_s is free of distortion, the intensity distribution in the plane of the reticle is also homogeneous

$$E_r(x,y) = E_r^0.$$

Since the scan path increases towards the edge of the field, the scanning energy $SE(x_r)$ in the plane of the reticle is a function of x_r

T0190

$$SE(x_r) = E_r^0 \int\limits_{\substack{\text{Scan path}\\ \text{at } x_r}} dy$$

The following equation applies:

T0191

$$SE(x_r) = E_r^0 \int\limits_{\substack{\text{Scan path}\\ \text{at } x_r}} dy = E_r^0 \cdot \left(\sqrt{\left(R_0 + \frac{\Delta r}{2}\right)^2 - x_r^2} - \sqrt{\left(R_0 - \frac{\Delta r}{2}\right)^2 - x_r^2} \right)$$

For $\Delta r < R_0$ and $x_r < R_0$, this equation can be expanded in a Taylor series, which is discontinued after the first order:

T0192

$$SE(x_r) = E_r^0 \int\limits_{\substack{\text{Scan path}\\ \text{at } x_r}} dy = E_r^0 \cdot \frac{1}{\sqrt{1 - \left(\frac{x_r}{R_0}\right)^2}}$$

The following parameters can be assumed for the arc shaped field 42 by way of example:

$R_0 = 100.0\text{mm}$

$\Delta r = 6.0\text{mm}; -3.0\text{mm} \leq r \leq 3.0\text{mm}$

$\alpha_0 = 30°$

With homogeneous intensity distribution E_r^0 the scanning energy $SE(x_r)$ rises at the edge of the field $x_r = 50.0$ mm, to

$SE(x_r = 50.0\text{mm}) = 1.15 \cdot SE(x_r = 0.0) = SE_{max}$.

The uniformity error produced is thus

p0200

$$Uniformity\,[\%] = 100\% \cdot \frac{SE_{max} - SE_{min}}{SE_{max} + SE_{min}} = 7.2\% \,.$$

The maximum scanning energy SE_{max} is obtained at the field edge (x_r=50.0mm), the minimum scanning energy SE_{min} is obtained at the center of the field (x_r=0.0).

With

R_0 = 200.0mm

Δr = 6.0mm; $-3.0mm \le r \le 3.0mm$

α_0 = 14.5°

we obtain

$$SE(x_r = 50.0) = 1.03 \cdot SE(x_r = 0.0).$$

The uniformity error produced is thus

p0201

$$Uniformity\,[\%] = 100\% \cdot \frac{SE_{max} - SE_{min}}{SE_{max} + SE_{min}} = 1.6\% \,.$$

The rise of the scanning energy toward the edge of the field is considerably smaller for larger radius R_0 of the arc shaped field 42 and smaller arc angles α_0.

The uniformity can be substantially improved pursuant to the invention if the field lens group is designed so that the image

formation in the plane of the reticle is distorted azimuthally, i.e., a location-dependent magnification $\beta_S(x_W) = \frac{s}{x_W}$ is introduced.

T0210

It is generally true that the intensity of irradiation E is defined as the quotient of the radiation flux dΦ divided by the area element dA struck by the radiation flux, thus:

T0211

$$E = \frac{d\Phi}{dA}$$

The area element for the case of the arc shaped field is given by

$$A = ds \cdot dr$$

ds: arc increment.

dr: radial increment.

If the azimuthal image formation is distorted, the distorted intensity E_r^V in the plane of the reticle behaves as the reciprocal of the quotient of the distorted arc increment ds^V divided by the undistorted arc increment $ds^{V=0}$:

T0212

$$\frac{E_r^V}{E_r^{V=0}} = \frac{dr \cdot ds^{V=0}}{dr \cdot ds^V} = \frac{1}{\frac{ds^V}{ds^{V=0}}}$$

Since with undistorted image formation the arc increment $ds^{V=0}$ is proportional to the x-increment dx_w at the rectangular field 41

$$ds^{v=0} \propto dx_w,$$

it follows that

T0220

$$E_r^V \propto \frac{1}{\frac{ds^V}{dx_w}}$$

T0221

The intensity $E_r^V(x_r)$ in the plane of the reticle can be controlled by varying the quotient $\frac{ds^V}{dx_w}$.

The relationship between scanning energy $SE(x_r)$ and azimuthal imaging magnification β_s is to be derived as follows:

T0222

$$SE(x_r) = \int_{\substack{\text{Scan path} \\ \text{at } x_r}} E(x_r, y_r)\,dy$$

The intensity $E(x_r, y_r)$ can be written as the product of the functions $g(r)$ and $f(s)$. The function $g(r)$ is only dependent on the radial direction r, the function $f(s)$ is only dependent on the azimuthal extent s:

$$E(x_r, y_r) = g(r) \cdot f(s).$$

For $\Delta r < R$ and $\Delta r < x_r$, g(r) should be independent of the x-position x_r in the plane of the reticle and f(s) should be independent of the y-position y_r in the plane of the reticle.

Since s and x_r, from

22

T0230

$$\sin\left(\frac{s}{R_0}\right) = \frac{x_r}{R_0}$$

are directly coupled to one another, $SE(x_r)$ can also be written as a function of s:

T0231

$$SE(s) = \int\limits_{\substack{\text{Scan path}\\ \text{at } s(x_r)}} f(s) \cdot g(r)dy$$

Since f(s) is independent of y_r, it follows that:

T0232

$$SE(s) = f(s) \cdot \int\limits_{\substack{\text{Scan path}\\ \text{at } s}} g(r)dy$$

and since

T0233

$$\frac{dr}{dy_r} = \cos\left(\frac{s}{R_0}\right)$$

then:

T0234

$$SE(s) = f(s) \cdot \frac{1}{\cos\left(\frac{s}{R_0}\right)} \cdot \int_{-\Delta r}^{+\Delta r} g(r)dr$$

The derivation of the distorted intensity E_r^V has shown the following proportionality for the function f(s):

$$f(s) \propto \frac{1}{\frac{ds}{dx_w}}$$

T0240

Since

$$\int_{-\Delta r}^{+\Delta r} g(r)dr$$

T0245

is independent of s, it follow that:

T0242

$$SE(s) \propto \frac{1}{\frac{ds}{dx_w} \cdot \cos\left(\frac{s}{R_0}\right)}$$

Considering the coupling of s and x_r, it follows that

T0243

$$SE(x_r) \propto \frac{1}{\frac{dx_r}{dx_w}}$$

T0244

From the quotient $\frac{dx_r}{dx_w}$ the scanning energy can thus be set directly, with x_r being the x-component of a field point on the arc shaped field 42 and x_w being the x-component of a field point on the rectangular field 41.

From a given curve of scanning energy $SE(x_r)$ or $SE(s)$ in the plane of the reticle, the azimuthal imaging magnification β_s can be calculated with these formulas.

T0250

$$SE(s) = c \cdot \frac{1}{\frac{ds}{dx_W} \cdot \cos\left(\frac{s}{R_0}\right)}$$

$$\frac{ds}{dx_W} = c \cdot \frac{1}{SE(s) \cdot \cos\left(\frac{s}{R_0}\right)}$$

$$x_W = c' \cdot \int_0^s SE(s') \cdot \cos\left(\frac{s'}{R_0}\right) ds'$$

The constant c' is obtained from the boundary condition that the edge of the rectangular field 41 at x_W^{Max} has to be imaged on the edge of the arc shaped field at $s^{max} = s_0$.

$s(x_w)$, and therefore the imaging magnification $\beta_s(x_w)$, is consequently known as a function of x_w:

T0251

$$\beta_S = \beta_S(x_W) = \frac{s(x_W)}{x_W}$$

The aforementioned equation for the azimuthal magnification β_s is to be solved by way of example for constant scanning energy $SE(x_r)$ in the plane of the reticle.

For constant scanning energy SE^0 in the plane of the reticle, the azimuthal imaging magnification is derived as follows:

$$x_W = c' \cdot \int_0^s SE^0 \cdot \cos\left(\frac{s'}{R_0}\right) ds' = c'' \cdot \int_0^s \cos\left(\frac{s'}{R_0}\right) ds'$$

T02-60

$$x_W = c'' \cdot \left[\sin\left(\frac{s'}{R_0}\right)\right]_0^s = c'' \cdot \sin\left(\frac{s}{R_0}\right)$$

$$s(x_W) = R_0 \cdot a\sin\left(\frac{x_W}{c''}\right)$$

and thus

T02-61

$$\beta_S(x_W) = R_0 \cdot \frac{a\sin\left(\frac{x_W}{c''}\right)}{x_W}$$

An illumination system will be considered below with:

Rectangular field 41 in a plane conjugated to the plane of the reticle:

$-8.75\text{mm} \leq x_w \leq 8.75\text{mm}$

$-0.5\text{mm} \leq y_w \leq 0.5\text{mm}$

Arc shaped field 42 in the plane of the reticle:

$-52.5\text{mm} \leq s \leq 52.5\text{mm}$

$-3.0\text{mm} \leq r \leq 3.0\text{mm}$

With the boundary condition

$s(x_w =- 8.75) = 52.5$ mm

the constant c" is obtained as follows:

c" = 954.983,

and thus

T0270

$$\beta_s = R_0 \cdot \frac{a\sin\left(\frac{x_w}{954.983}\right)}{x_w}$$

If the design of the field lens group generates this curve of the azimuthal imaging magnification, then a constant scanning energy is obtained in the plane of the reticle for the system defined above by way of example.

With variation of the azimuthal magnification β_s, it is necessary for use in lithographic systems to consider that the field lens group, in addition to field formation, also determines the imaging of the secondary light sources, or the aperture stop plane, into the entrance pupil of the projection objective. This as well as the geometric boundary conditions does not permit an arbitrarily large distortion correction.

The previously described uniformity correction is not restricted to the illumination system with a faceted mirror described by way of example, but can be used in general. By distorting the image formation in the reticle plane perpendicular to the scanning direction the intensity distribution, and thus the scanning energy distribution, can be controlled.

Typically, the illumination system contains a real or virtual plane with secondary light sources. This is always the case, in particular, with Köhler illumination systems. The aforementioned real or virtual plane is imaged in the entrance pupil of the objective using the field lens group, with the arc shaped field being produced in the pupil plane of this image formation. The pupil plane of the pupil imaging is, in this case, the plane of the reticle.

Some examples of embodiment of illumination systems will be described below, where the distribution of scanning energy is controlled by the design of the field lens group. The general layout of the illumination systems is shown in Figure 2. The optical data of the illumination system are summarized in table 1.

T0290

TABLE 1

	Ref. No. in Fig. 2	Surface parameters (Radius R, conical constant K)	Thickness d along the optical axis [mm]	Angle between surface normal and the optical axis α_x [°]
Source	200	∞	100.000	0.0
Collector mirror	12	R=-183.277mm K=-0.6935	881.119	0.0
Mirror with field facets	22	∞	200.000	7.3
Aperture stop plane	23	∞	1710.194	0.0
1^{st} Field mirror	24	R_y=-7347.291mm R_x=-275.237 K_y=-385.814 K_x=-3.813	200.000	80.0
2^{nd} Field mirror	25	R_y=14032.711 R_x=1067.988 K_y=-25452.699 K_x=-667.201	250.000	80.0
Reticle	26	∞	1927.420	2.97
Exit pupil	27	∞		

The illumination system of Figure 2 and Table 1 is optimized for a Laser-Produced-Plasma source 200 at λ=13nm with a source diameter of 50µm. The solid angle Ω of the collected radiation is $\Omega \approx 2\pi$.

The mirror 22 with field facets has a diameter of 70.0mm, and the plane field facets have a rectangular shape with x-y dimensions of 17.5mm x 1.0mm. The mirror 22 consists of 220 field facets. Each facet is tilted relative to the local x- and y-axis to overlay the

images of the field facets at least partly in the image plane 26. The field facets at the edge of mirror 22 have the largest tilt angles in the order of 6°. The mirror 22 is tilted by the angle α_x=7.3° to bend the optical axis by 14.6°.

The aperture stop plane 23 in this example is not accessible.

The first and second field mirrors 24 and 25 are grazing incidence mirrors. Each of them bends the optical axis by 160°. The field mirror 24 is a concave mirror, and the mirror 25 is a convex mirror. They are optimized to control the illumination intensity, the field shaping and the pupil imaging. In the following embodiments only these two mirrors will be replaced. Their position and tilt angle will always be the same. It will be shown, that by modifying the surface shape, it is possible to change the intensity distribution while keeping the pupil imaging and the field shaping in tolerance.

The arc shaped field in the plane of the reticle 26 can be described by

R_0 = 100.0mm

Δr = 6.0mm; $-3.0\text{mm} \le r \le 3.0\text{mm}$

α_0 = 30°

The reticle 26 is tilted by α_x=2.97° in respect to the optical axis. The position of the exit pupil 27 of the illumination system is defined by the given design of the projection objective.

A notable feature of the present invention is the asphericity of the mirror surfaces that provide a favorable uniformity of scanning energy on the one hand, and on the other hand a favorable

telecentricity. While the asphericity of the mirror surfaces will be varied, the tilt angles and spacing of the mirrors are to be kept constant.

The following examples are presented and compared with reference to the following parameters:

T0310

- $$Uniformity[\%] = 100\% \cdot \frac{SE_{max} - SE_{min}}{SE_{max} + SE_{min}}$$

  SE_{max}: maximum scanning energy in the illuminated field.
  SE_{min}: minimum scanning energy in the illuminated field.

- maximum telecentricity error Δi_{max} over the illuminated field in the reticle plane

$$\Delta i_{max} = [i_{act} - i_{ref}]_{max} \text{ in [mrad]}$$

i_{act}: angle of a centroid ray with respect to the plane of the reticle at a field point.

i_{ref}: angle of a chief ray of the projection objective with respect to the plane of the reticle at the same field point.

The maximum telecentricity error Δi_{max} will be calculated for each field point in the illuminated field. The direction of the centroid ray is influenced by the source characteristics and the design of the illumination system. The direction of the chief ray of the projection objective in the plane of the reticle depends only on the design of the projection objective. Typically the chief rays hit the wafer plane telecentrically.

To get the telecentricity error in the wafer plane the telecentricity error in the reticle plane has to be divided by the magnification of the projection objective. Typically the projection objective is a reduction objective with a magnification of β=-0.25, and therefore the telecentricity error in the wafer plane is four times the telecentricity error in the reticle plane.

- geometric parameters of the first field mirror: R_x, R_y K_x, K_y

- geometric parameters of the second field mirror: R_x, R_y K_x, K_y

Both field mirrors are toroidal mirrors with surface parameters defined in the x- and y-direction. R describes the Radius, K the conical constant. It is also possible to vary higher aspherical constants, but in the examples shown below only the radii and conical constants will be varied.

1st example of embodiment:

For field mirrors with purely spherical x and y cross sections, the following characteristics are obtained:

- Uniformity = 10.7%
- Δi_{max} = 0.24 mrad
- Field mirror 1: R_x = -290.18, R_y = -8391.89, K_x = 0.0, K_y = 0.0
- Field mirror 2: R_x = -1494.60, R_y = -24635.09, K_x = 0.0, K_y = 0.0

The curve of the scanning energy over the x direction in the plane of the reticle is plotted in Figure 5 as a solid line 51.

Because the system is symmetric to the y-axis, only the positive part of the curve is shown. The scanning energy is normalized at the center of the field at 100%. The scanning energy rises toward the edge of the field to 124%. The calculation takes into consideration only the imaging of one representative field facet, in this case the central field facet, which is assumed to be a homogenous radiating surface.

However, this relationship is also maintained for the entire system, as shown by the result for all of the field facets in Figure 6. The curves of Figure 6 are the result of a simulation with a Laser-produced-Plasma source 200 and the whole illumination system according to Figure 2. The solid line 61 represents the scanning energy for toroidal field mirrors of the 1st embodiment without conic constants.

A comparison of the solid lines or the dashed lines of Figure 5 and Figure 6 shows similar characteristics, that is they are almost identical. The curves in Figure 5 were calculated (1) by considering only a homogeneously radiating rectangular field, i.e., the central field facet, and (2) the Taylor series was discontinued after the first series. However, the curves in Figure 6 are a result of a simulation with the real illumination system. It is apparent from a comparison of the curves of Figure 5 and Figure 6 that the theoretical model can be used to predict scanning energy distribution, including that of a multifaceted system, and that the following approximations are possible:

- Reduction of the problem to the imaging of a rectangular field, in this case the central field facet.
- $\Delta r < R$: Discontinuation of the Taylor series after the first order.

Systems comprising toroidal field mirrors in which the conic constants can be varied and in which the field mirrors are post-optimized, with their tilt angle and their position being retained, will be presented below.

2nd example of embodiment:

- Uniformity = 2.7%
- Δi_{max} = 1.77 mrad
- Field mirror 1: R_x = -275.24, R_y = -7347.29, K_x = -3.813, K_y = -385.81
- Field mirror 2: R_x = 1067.99, R_y = 14032.72, K_x = -667.20, K_y = -25452.70

The dashed curve 52 in Figure 5 shows the curve of scanning energy expected from the design for the central field facet; the curve scanning energy obtained with the entire system of all of the field facets is shown as dashed curve 62 in Figure 6. The improvement of the scanning uniformity is obvious using the conical constants in the design of the field mirrors.

The necessary surface corrections on the two field mirrors 24 and 25 of Figure 2 are shown in the illustrations of Figure 7 and Figure 8 as contour plots. The mirrors are bounded according to the illuminated regions on the mirrors. The bounding lines are shown as reference 71 in Figure 7 and reference 81 in Figure 8. The contour plots show the sagitta differences of the surfaces of the first and second embodiment in millimeters.

For the first field mirror 24 the maximum sagitta difference is on the order of magnitude of 0.4mm in Figure 7. There is also a sign reversal of the sagitta differences.

For the second field mirror 25 the maximum sagitta difference is on the order of magnitude of 0.1mm in Figure 8.

The second embodiment was optimized to get the best improvement of the scanning uniformity accepting an arising telecentricity error. The telecentricity violation of 1.77mrad in the reticle plane of the second embodiment is problematic for a lithographic system.

The following examples demonstrate embodiments in which the maximum telecentricity violation in the plane of the reticle is less or equal 1.0 mrad.

The design shown in the example of embodiment 1 is the starting point for the design of the field mirrors in the following examples. In each example, different sets of surface parameters have been optimized.

3rd example of embodiment:

Optimized parameters $R_x^{1st\ mirror}, R_y^{1st\ mirror}, K_x^{1st\ mirror}, K_y^{1st\ mirror}, R_x^{2nd\ mirror}, R_y^{2nd\ mirror}, K_x^{2nd\ mirror}, K_y^{2nd\ mirror}$.

- Uniformity = 4.6%
- ΔI_{max} = 1.00 mrad
- Field mirror 1: R_x = -282.72, R_y = -7691.08, K_x = -2.754, K_y = -474.838

- Field mirror 2: $R_x = 1253.83$, $R_y = 16826.99$, $K_x = -572.635$, $K_y = -32783.857$

4th example of embodiment:

Optimized parameters $R_x^{1st\ mirror}, K_x^{1st\ mirror}, K_y^{1st\ mirror}, R_x^{2nd\ mirror}, K_x^{2nd\ mirror}, K_y^{2nd\ mirror}$.

- Uniformity = 5.1%
- $\Delta i_{max} = 1.00$ mrad
- Field mirror 1: $R_x = -285.23$, $R_y = -8391.89$, $K_x = -2.426$, $K_y = -385.801$
- Field mirror 2: $R_x = 1324.42$, $R_y = 24635.09$, $K_x = -568.266$, $K_y = -31621.360$

5th example of embodiment:

Optimized parameters $R_x^{1st\ mirror}, K_x^{1st\ mirror}, R_x^{2nd\ mirror}, K_x^{2nd\ mirror}$.

- Uniformity = 5.1%
- $\Delta i_{max} = 1.00$ mrad
- Field mirror 1: $R_x = -280.08$, $R_y = -8391.89$, $K_x = -2.350$, $K_y = 0.0$
- Field mirror 2: $R_x = 1181.53$, $R_y = 24635.09$, $K_x = -475.26$, $K_y = 0.0$

6th example of embodiment:

Optimized parameters $K_x^{1st\ mirror}, K_y^{1st\ mirror}, K_x^{2nd\ mirror}, K_y^{2nd\ mirror}$.

- Uniformity = 6.0%

- Δi_{max} = 1.00 mrad
- Field mirror 1: R_x = -290.18, R_y = -8391.89, K_x = -2.069, K_y = -290.182
- Field mirror 2: R_x = 1494.60, R_y = 24635.09, K_x = -503.171, K_y = -1494.602

7th example of embodiment:

Optimized parameters $K_x^{1st\ mirror}, K_x^{2nd\ mirror}$.

- Uniformity = 7.0%
- Δi_{max} = 1.00 mrad
- Field mirror 1: R_x = -290.18, R_y = -8391.89, K_x = -1.137, K_y = 0.0
- Field mirror 2: R_x = 1494.60, R_y = 24635.09, K_x = -305.384, K_y = 0.0

8th example of embodiment:

Optimized parameters $R_x^{1st\ mirror}, R_y^{1st\ mirror}, K_x^{1st\ mirror}, K_y^{1st\ mirror}$.

- Uniformity = 7.8%
- Δi_{max} = 1.00 mrad
- Field mirror 1: R_x = -288.65, R_y = -8466.58, K_x = -0.566, K_y = 139.337
- Field mirror 2: R_x = 1494.60, R_y = 24635.09, K_x = 0.0, K_y = 0.0

9th example of embodiment:

Optimized parameters $R_x^{1st\ mirror}, K_x^{1st\ mirror}, K_y^{1st\ mirror}$.

- Uniformity = 7.8%
- Δi_{max} = 1.00 mrad
- Field mirror 1: R_x = -288.59, R_y = -8391.89, K_x = -0.580, K_y = 111.346
- Field mirror 2: R_x = 1494.60, R_y = 24635.09, K_x = 0.0, K_y = 0.0

10th example of embodiment:

Optimized parameters $R_x^{1st\ mirror}, K_x^{1st\ mirror}$.

- Uniformity = 8.1%
- Δi_{max} = 1.00 mrad
- Field mirror 1: R_x = -288.45, R_y = -8391.89, K_x = -0.574, K_y = 0.0
- Field mirror 2: R_x = 1494.60, R_y = 24635.09, K_x = 0.0, K_y = 0.0

11th example of embodiment:

Optimized parameters $K_x^{1st\ mirror}, K_y^{1st\ mirror}$.

- Uniformity = 8.5%
- Δi_{max} = 1.00 mrad
- Field mirror 1: R_x = -290.18, R_y = -8391.89, K_x = -0.304, K_y = -290.182
- Field mirror 2: R_x = 1494.60, R_y = 24635.09, K_x = 0.0, K_y = 0.0

12th example of embodiment:

Optimized parameter $K_x^{1st\ mirror}$.

- Uniformity = 8.6%
- Δi_{max} = 1.00 mrad
- Field mirror 1: R_x = -290.18, R_y = -8391.89, K_x = -0.367, K_y = 0.0
- Field mirror 2: R_x = 1494.60, R_y = 24635.09, K_x = 0.0, K_y = 0.0

The results for the various examples of embodiment are summarized in Table 2, with the optimized parameters designated with an "x".

TABLE 2

R_x^{1st} mirror	R_y^{1st} mirror	K_x^{1st} mirror	K_y^{1st} mirror	R_x^{2nd} mirror	R_y^{2nd} mirror	K_x^{2nd} mirror	K_y^{2nd} mirror	Uniformity [%]	Telecentricity error in the reticle plane Δi_{max} [mrad]
Without conic constants								10.7	0.24
Variation, field mirror 1									
		X						8.6	1.0
		X	X					8.5	1.0
X		X						8.1	1.0
X		X	X					7.8	1.0
X	X	X	X					7.8	1.0
Variation, field mirrors 1 + 2									
		X				X		7.0	1.0
		X	X			X	X	6.0	1.0
X		X		X		X		5.1	1.0
X		X	X	X		X	X	5.1	1.0
X	X	X	X	X	X	X	X	4.6	1.0

T0390

Table 2 shows that field mirror 1 and field mirror 2 improve the scanning uniformity to almost the same extent, with the principal fraction of this being carried by the x parameters, which ultimately determine the azimuthal magnification scale β_s.

While only static correction of uniformity was examined with the exemplary embodiments described so far, in which essentially only the surface was "warped", an active variant of the invention will be described below. Actuation in this case can occur by means of mechanical actuators. A possible actuator can be a piezo-element at the rear side of a field mirror to vary the shape of the mirror by changing the voltage to the piezo-element. As stated above, great improvements of uniformity can be produced even when only the x surface parameters are changed. If only the conic constants in the x direction are varied, the sagitta differences have the same algebraic sign over the entire surface, which is advantageous for the surface manipulation. Figure 9 and Figure 10 show the sagitta differences between the field mirrors of embodiment #6 and embodiment #1. The conic constants in the x direction were varied here for field mirror 1 and 2. The maximum sagitta differences are 250 μm for the first field mirror 24 and 100 μm for the second field mirror 25. Uniformity is improved from 10.7% to 7.0% with an additional telecentricity violation of 1.0 mrad in the plane of the reticle. This telecentricity violation corresponds to 4.0 mrad in the plane of the wafer, if the projection objective has a magnification of $\beta = -0.25$. Accordingly the uniformity of scanning energy can be corrected by ± 3.7% by active manipulation on the mirrors of the field lens group.

When only the conic constants in the x direction are varied, the sagitta changes depend almost only on x. The lines with the same sagitta difference are nearly parallel to the y-axis, which is, in this example, the scanning direction.

The sagitta distribution pfh_{ref} of the reference surfaces (1st embodiment) of the field mirrors can be described by:

T0410

$$pfh_{ref}(x,y)=\frac{\frac{1}{R_x}\cdot x^2+\frac{1}{R_y}\cdot y^2}{1+\sqrt{1-\left(\frac{1}{R_x}\right)^2\cdot x^2-\left(\frac{1}{R_y}\right)^2\cdot y^2}}$$

x and y are the mirror coordinates in the local coordinate system of the mirror surface. R_x and R_y are the radii of the toroidal mirror.

The sagitta distribution pfh_{act} of the manipulated surfaces of the field mirrors can be described by:

T0411

$$pfh_{ref}(x,y)=\frac{\frac{1}{R_x}\cdot x^2+\frac{1}{R_y}\cdot y^2}{1+\sqrt{1-(1+K_x)\cdot\left(\frac{1}{R_x}\right)^2\cdot x^2-(1+K_y)\cdot\left(\frac{1}{R_y}\right)^2\cdot y^2}}$$

K_x and K_y are the conical constants.

For the sagitta difference Δpfh, this gives:

$$\Delta pfh(x,y)=pfh_{act}(x,y)-pfh_{ref}(x,y)$$

In embodiment #1:

Field mirror 1: $R_x = -290.18$, $R_y = -8391.89$, $K_x = 0.0$, $K_y = 0.0$
Field mirror 2: $R_x = -1494.60$, $R_y = -24635.09$, $K_x = 0.0$, $K_y = 0.0$

In embodiment #6:
Field mirror 1: $R_x = -290.18$, $R_y = -8391.89$, $K_x = -1.137$, $K_y = 0.0$
Field mirror 2: $R_x = 1494.60$, $R_y = 24635.09$, $K_x = -305.384$, $K_y = 0.0$

Preferably, the actuators or mechanical regulators are placed on the mirrors on equipotential lines 92, 102 (sites of equal sagitta difference). In the example of embodiment #6, these rows of identical actuators run almost parallel to the y axis, and therefore, it is unnecessary to control a two-dimensional field of actuators, but it suffices to control only a row of different actuator banks.

For example, on the second field mirror an arrangement of actuator rows can be proposed as shown in Figure 11. The second field mirror is shown in the plan view (x-y-view) at the top and side view (x-z-view) at the bottom of Figure 11. In the plan view the actuator beams 5′, 4′, 3′, 2′, 1′, 0, 1, 2, 3, 4, 5 are arranged along equipotential lines. Because of the symmetry regarding the y-axis the corresponding actuator beams 5 and 5′, or 4 and 4′, or 3 and 3′, or 2 and 2′, or 1 and 1′ can be activated with the same signal. The actuators in the plan view are represented by lines, and in the side view by arrows.

An industrial implementation would be to design the entire row of actuators as actuator beams 5′, 4′, 3′, 2′, 1′, 0, 1, 2, 3, 4, 5. When the beam is actuated, the entire row of actuators is raised or lowered.

The distances between the actuator beams can be chosen dependent on the gradient of the sagitta differences. For high values of the gradient a dense arrangement of the actuator beams is necessary, for low values of the gradient the distances can be increased. In the example of Figure 10 the gradient of the sagitta differences is high at the edges of the illuminated field, so more actuator beams are at the edge of the field than in the center as shown in Figure 11.

An active correction of uniformity can be accomplished as follows using the actuators described above.

The curve of scanning energy $SE_{Standard}(x_r)$ in the plane of the reticle is established based on the geometric design of the field lens group.

Now the scanning energy $SE_{wafer}(x_{wafer})$ in the plane of the wafer is measured, including all coating, absorption, and vignetting effects.

For the lithographic process, $SE_{wafer}(x_{wafer})$ has to be independent of the x-position x_w in the plane of the wafer. If this is not the case, the x_w-dependent offset has to be addressed by the illumination system.

Since the imaging of the reticle plane to the wafer plane is almost ideal imaging, $SE_{wafer}(x_{wafer})$ can be converted directly into the plane of the reticle $SE_{wafer}(x_r)$ using the given magnification of the projection objective.

If the design reference $SE_{Standard}(x_r)$ and the measured distribution $SE_{wafer}(x_r)$ are normalized at 100% for $x_r = 0.0$, then the

necessary correction of the surfaces of the field mirrors can be calculated from the difference $SE_{Des}^{akt}(x_r)$:

$$SE_{Des}^{akt}(x_r) = SE_{wafer}(x_r) - SE_{Standard}(x_r$$

$SE_{Des}^{akt}(x_r)$ determines the azimuthal magnification β_s, and from this the necessary corrections for the field lens group.

If there is a difference $SE_{Des}^{akt}(x_r)$ between the target $SE_{Standard}(x_r)$ and actual values $SE_{wafer}(x_r)$ due to time-dependent or illumination setting-dependent effects for example, the uniformity of the scanning energy can be corrected by the actuators described above within certain limits. Up to ± 2.5% uniformity can be corrected with one manipulable field mirror, and up to ± 5.0% with two manipulable field mirrors.

In case of static deviations, e.g., deviations from coating effects, absorption effects, etc., which are known in the design phase, these effects can be taken into consideration in a modified field lens group design, and correction with actuators is then unnecessary.

Intensity loss-free control of scanning energy is achieved by the present invention, where the field-dependent scan path, the coating, absorption, and vignetting effects, if known, can be taken into account in the static design of the field lens group. Furthermore, the invention proposes dynamic control with active field mirrors for time-dependent or illumination setting-dependent effects. If a telecentricity error of ± 4.0 mrad is allowed in the plane of the wafer, the uniformity correction can be up to ± 5%.

In Figure 12 a projection exposure system comprising an Laser-Produced-Plasma source as light source 120, an illumination system 121 corresponding to the invention, a mask 122, also known as a reticle, a positioning system 123, a projection objective 124 and a wafer 125 to be exposed on a positioning table 126 is shown. The projection objective 124 for EUV lithography is typically a mirror system with an even number of mirrors to have reticle and wafer on different sides of the projection objective 124.

Detection units in a reticle plane 128 and in a wafer plane 129 are provided to measure the intensity distribution inside the illuminated field. The measured data are transferred to a computation unit 127. With the measured data the scanning energy and scanning uniformity can be evaluated. If there is a difference between the predetermined and the measured intensity distribution, the surface corrections are computed. The actuator drives 130 at one of the field mirrors are triggered to manipulate the mirror surface.

It should be understood that various alternatives and modifications could be devised by those skilled in the art. The present invention is intended to embrace all such alternatives, modifications and variances that fall within the scope of the appended claims.